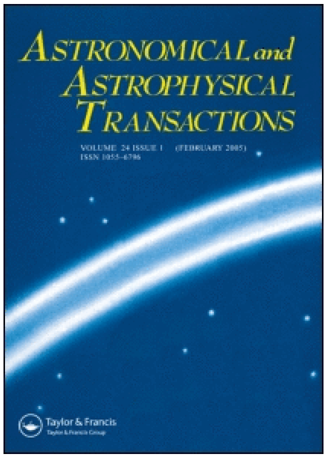

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ORION NEBULA: IONIZATION STRUCTURE AND SOME PARAMETERS BY RRL

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Preliminary results of the Ori A region mapping based on hydrogen (H), helium (He) and Carbon (C) Radio Recombination lines (RRL) are presented. Observations were done using both the 32 m VLBI dish of Medicina (Italy) and the Pushchino RT-22 dish (Russia).

KEY WORDS ISM: abundances – HII regions – Radio Lines: Orion Nebula

1 INTRODUCTION

Helium abundance, $y = N(\mathrm{He})/N(\mathrm{H})$, is one of the main experimental parameters of both Cosmology and Astrophysics (Schmid-Bergk, 1981; Walker *et al.*, 1991), which can be obtained by RRL observations in HII regions (Schmid-Bergk, 1981; Sorochenko and Tsivilev, 1996). Actually these observations, as well as other methods like optical line measures, give the ratio of the ionized component. In fact, the ratio between He and H RRLs gives $y^+ = N(\mathrm{He}^+)/N(\mathrm{H}^+)$ and the problem of obtaining y from y^+ is still open.

As for the Orion Nebula, H and He RRL mapping at $\sim$ 5 GHz (Jaffe and Pankonin, 1978; Pankonin *et al.*, 1980) showed y^+ decreasing from the HII center outwards according to standard schemes. On the other hand observation at 22 GHz (Tsivilev *et al.*, 1986) showed the inverse dependence: y^+ increases from $\sim$ 9% in the center up to $\sim$ 11–12% at a distance of $\sim 3'$ from the center. The authors explained this inverse behaviour on the basis of a 'blister type' structure (e.g. no classic) with two different y^+ behaviours: one for the core and another for the halo of this HII region. The y^+ decrease with distance from the center at the lower frequency (5GHz) was explained by strong (but different for H and He RRLs) non-LTE effects which are negligible at the higher (22 GHz) frequency. Gordon and Walmsley (1990) observed H, He40α RRL in the center of the nebula and in four positions 1′ away from it, but individual y^+ values were not presented. Nevertheless, using their presented spectra, $y^+ = 10.5\%$ and $y^+ = 11\%$ (averaged) were estimated for the center and the peripheral positions, respectively. Moreover, Peimbert *et al.* (1988) found y^+ decreasing from the center outwards in 41α and 53α observations. In this case the angular resolutions (18.5″ and 39.5″) were much better than in other observations (2.6′ and 1′, Tsivilev *et al.*, 1986; Gordon and Walmsley, 1990) and consequently different size scales were characterized. Similarly, at optical wavelengths: Peimbert and Torres-Peimbert (1977) found y^+ decreasing from the center while Baldwin *et al.* (1991) obtained $y^+ = 8.8\%$ nearly constant out to $\sim 5'$ from the center.

Such a disagreement between optical and radio measurements of y^+ has stimulated a joint project to further investigate the ionization structure in the Orion Nebula as well as to improve the knowledge of its physical parameters. The project should provide RRL maps of this HII region at two frequencies with the same beamwidth. This paper reports results obtained from the analysis of the first observation run.

2 OBSERVATIONS AND DATA REDUCTION

The 66α (22 GHz frequency, Medicina VLBI dish) and the 56α (36 GHz frequency, Pushchino RT-22) H, He and C RRL were observed in 14 positions (see Figure 1) towards the Orion Nebula.

The angular resolution (2′) was the same for both telescopes; the beam efficiencies (η_B) and system temperatures (T_{sys}) were $\eta_B = 44\%$, $T_{sys} \simeq 150K$ and $\eta_B = 33\%$, $T_{sys} \simeq 200K$ for the Medicina and Pushchino radiotelescopes respectively.

The Medicina observations were carried out with a 16–20 MHz bandwidth, a 1024 channel autocorrelator (0.88 km s^{-1} velocity resolution), using the standard position switching observing technique with 4 minutes integration on the source followed by 4 minutes integration on a reference position. Total integration times range from 0.5 to 9 hours depending on the line strength.

RT-22 observations (spectral and continuum simultaneous observations) were carried out with 128 channels, a 64 MHz bandwidth filter bank spectral analyzer (4.11 km s^{-1} velocity resolution). A ON–ON (Berulis *et al.*, 1983) observing technique based on beam switching was adopted, with $\sim$ 5 minutes on source integration time. Integration times were from 6 to 9 hours for Ori A and positions 1–4, while for positions 5–9 they were from 21 to 25 hours.

All the spectra obtained for each position were averaged, and fitted with a Gaussian profile using a non-linear least square method (Smirnov and Tsivilev, 1982).

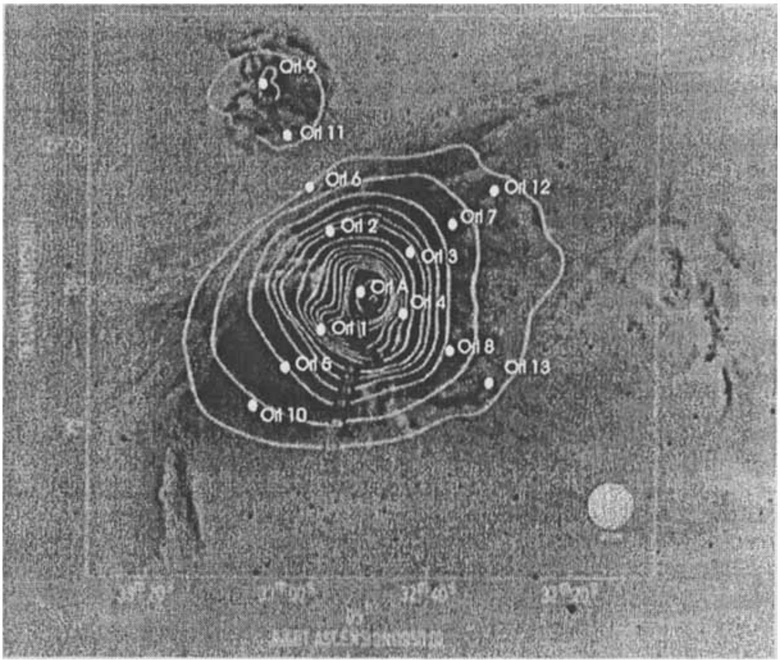

Figure 1 Observed positions superimposed on an optical map ($H\alpha$ and [*NII*] – image (Hua and Loise, 1982)) and on a 23 GHz contour map of the Orion Nebula (Wilson and Pauls, 1984)

3 RESULTS

A) IONIZED HELIUM DISTRIBUTION. Figure 2 shows the y^+ value distribution, from which can be seen a maximum (north-east of the center, corresponding to the star Ori θ^1 C) an undoubted decrease in the southern part. This picture is in agreement with the result of Pankonin *et al.*, (1980) whose 5 GHz mapping showed different y^+ behaviour along different directions with a strong decrease in the south-east part. There is some minimum in the center, then the y^+ increases until about $2'$ from the center then decreases again. Qualitatively, this picture is in agreement with the asymmetric model (Tsivilev *et al.*, 1986) where the He^+ region size was smaller than that of H^+ but with a different power for the core and for the envelope.

This may also explain the discrepancy in optical data between Peimbert and Torres-Peimbert (1977) and Baldwin *et al.* (1991), because of the different directions from the center they observed.

B) BLISTER STRUCTURE AND HELIUM ABUNDANCE. Figure 2 presents the average $V_{\rm LSR}$ and ΔV of hydrogen lines (spectra averaged over the ring) as a function of distance from the center: $V_{\rm LSR}$ values become more negative with distance, up to 2–4 arcmin, then they increase, while ΔV values increase with distance. This behaviour is in agreement with other RRL observations, i.e. with the H76a

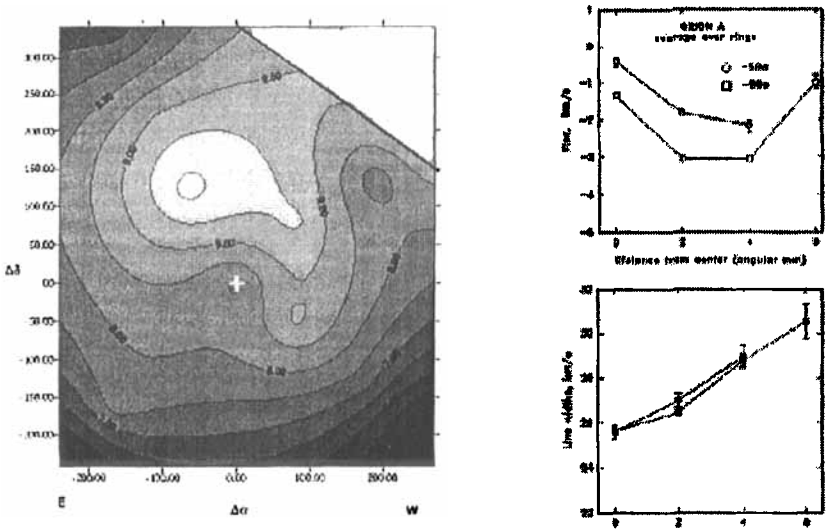

Figure 2 Map of $y^+ = N(He^+) = N(H^+)$ value (left). The cross marks the center and the scale is in angular seconds. Plots on the right represent Radial velocities (upper) and Widths (lower) of hydrogen lines vs the angular distance (minutes) from the center.

mapping of Pankonin *et al.* (1979). The combination of these data ($V_{LSR}(R), \Delta V(R)$ and $y^+(R)$) qualitatively supports the 'blister'-type model, where the HII region, located at the boundary of a molecular cloud, has an asymmetric expansion structure, expanding mainly toward the observer along the line of sight, or with a small inclination angle (Pankonin *et al.*, 1979).

Radio recombination lines of carbon were seen at practically all positions, depending on the sensitivity. Their radial velocities (V_{LSR}) lay in the interval: V_{LSR} from +8 to +11 km s^{-1}, while H and He RRLs have V_{LSR} from +1 to −6 km s^{-1}. Since carbon V_{LSR} refers rather to molecular cloud motion and hydrogen V_{LSR} refers to ionized material motion, the difference again indicates asymmetric ('blister') expansion of the HII region (relative to the associated molecular cloud) toward the observer.

The He^+ region size being smaller than that of H^+, it is necessary to correct observed y^+ values for the ionization structure to obtain a true helium abundance. But, according to a 'blister'-type model (Tsivilev, 1991) part or the whole of the envelope can be density limited, that is, most of the ionizing photons can go away freely. In this case the size of both the He^+ and H^+ zones coincide and the measured helium abundance is true in that place. The region where a maximum of y^+ has been measured can be considered to be in these conditions. For this hypothesis a true value of $y = 10.0(\pm 0.9)\%$ has been obtained from reliable data in positions 2 and 3 (Figure 2), which are close to the map maximum. This value is in excellent agreement with the optical value $y = 10.0(\pm 0.5)\%$ (Peimbert and Torres-Peimbert, 1977) where a correction for the ionization structure has been made.

C) IONIZING STAR AND ELECTRON TEMPERATURE. It is known that the Orion A HII region is ionized mainly by a star of O6V spectral type. But there are some discrepancies in the calibration of the effective temperature (T_{ef}) of this star, which spans from 37000 K (Rubin, 1984) to 39600 K (Baldwin *et al.*, 1991). Since the size ratio of He^+ and H^+ regions depends on the star effective temperature and assuming such a temperature to be 39600 K, both the He^+ and the H^+ regions coincide or, at least the He^+ region may overlap the H^+ one (Gulyaev *et al.*, 1997). In this case the star effective temperature must be closer to $\sim$ 37000 K, and the He^+ region is smaller than the H^+ one. The obtained LTE electron temperatures are in the interval: 7400–8800 K.

Acknowledgements

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